Finite Element Analysis of Laser Cladding Process

[1]Devendra Kumar Gautam, [2]Audhesh Narayan, [3]Satish Kumar, [4]Ajaya Bharti

Department of Applied Mechanics, Motilal Nehru National Institute of Technology Allahabad, Prayagaraj Uttar Pradesh 211004

[1]gautamdevendra070@gmail.com, [2]anarayan@mnnit.ac.in, [3]satistme@mnnit.ac.in, [4]abharti@mnnit.ac.in

Abstract

Laser cladding (LC) is a novel manufacturing process that can be used for coating and prototyping, among other things. In most situations, complex processing processes and the development and growth of thin clads in the micrometer to millimeter range remain unsolved. A thermo-mechanical finite element model with a Gaussian moving heat source and an element birth and death technique has been developed to describe powder injection laser cladding of CPM9V over H13 tool steel. The temperature distribution over the clad material is determined using Ansys software and a finite element analysis. During the FEA change of laser power and scanning speed, I discovered a temperature gradient. I also discovered a correlation between temperature gradient and laser power, as well as a correlation between temperature gradient and scanning speed. This understanding should come in useful when it comes to repairing structures that are subjected to cyclic thermo-mechanical loads.

Keywords. — Heat transfer, FEA, Laser Cladding Process, Simulation.

1. INTRODUCTION

The laser cladding is a weld forming process and is costing technology that complements thermal spray. It is gradually used as an alternative to the Plasma Transferred Arc (PTA) welding and simply outperforms conventional welding methods as the Tungsten Inert Gas (TIG) designed for advanced weld repairing applications[1]. The heat source's laser beam is dimmed on the workpiece with a predetermined spot size during the LC process. A powder nozzle deli vers the powder coated material into the melting area with inert gas. Single grooves, entire layers, or even huge agglomerates are deposited by moving laser beam and powder nozzles over the workpiece surface. LC process is a material deposition method in which a wire or powder material is melted and consolidated using a laser to clad part of the substrate or to fabricate a shape close to the array. It has ability to mix two or more powders and control the feed rate of each powder stream makes laser coating a versatile process for manufacturing heterogeneous components or functional grade material[2].

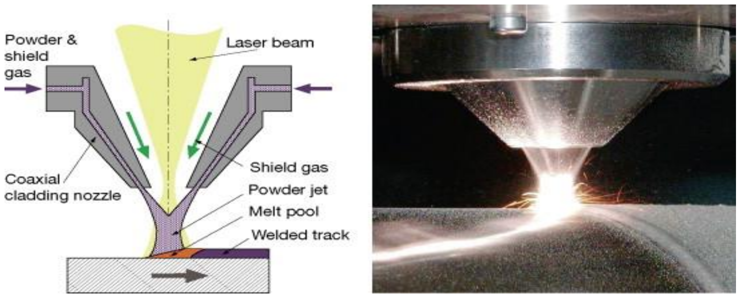

Figure 1. Laser Cladding Process[3]

2. FINITE ELEMENT MODELLING OF LC PROCESS

To determine simulation results of temperature dispersion, a FEM-based transient thermal model was constructed. Different materials Such as the clad material CPM9V vanadium carbide steel and substrate material H13 tool steel are used such as the work material with a size of the clad material 6 × 3 × 0.6 mm and substrate material 6 × 6 × 6 mm for performing the FEM analysis[4]. The model is further discredited into smaller size elements for more obtain more precise results. Standard ANSYS software was used to estimate the temperature distribution inside the work material during the laser cladding process.

2.1 Three-dimensional (3-D) Model

A semi-symmetric model measuring 6 mm 6 mm 6 mm was designed for simulation. It is intended to conduct a combined investigation of these thermal and mechanical processes. Eight nodded coupled temperature distributions were used to calculate the influence of the thermal stress generated throughout this operation.

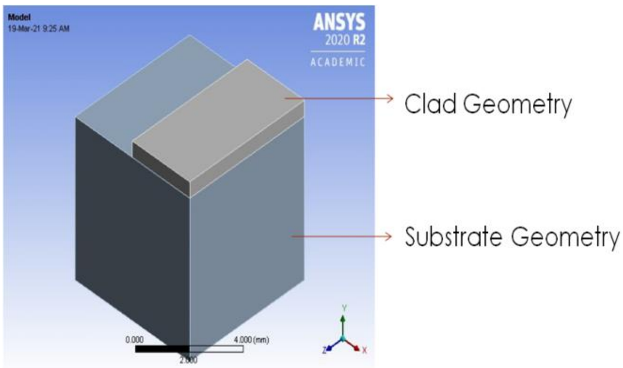

Figure 2. Geometry of the 3-D model

In 3-D model 8- Nodded Fine Meshing of the both clad and substrate body. The node has 9790 elements, and the total number of elements is 1968.

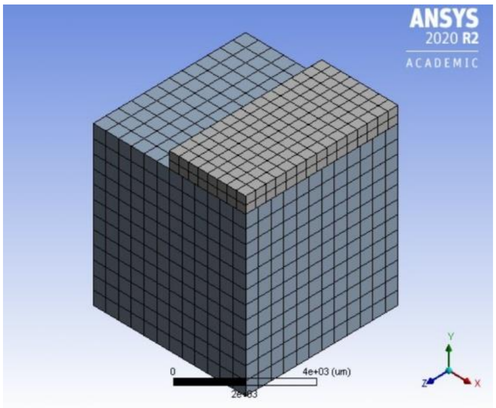

Figure 3. Meshing of 3-D Model

2.2 Loading and boundary condition

With a linear decrease in heat input with depth of penetration, the source is predicted to emit a Gaussian moving heat source distribution of laser power. Heat transfer via convection with a heat transfer coefficient of 15 W/m^2K is one of the thermal boundary conditions and heat transfer by radiation with emissivity of 0.3 lead to thermal damage of the surfaces[5].

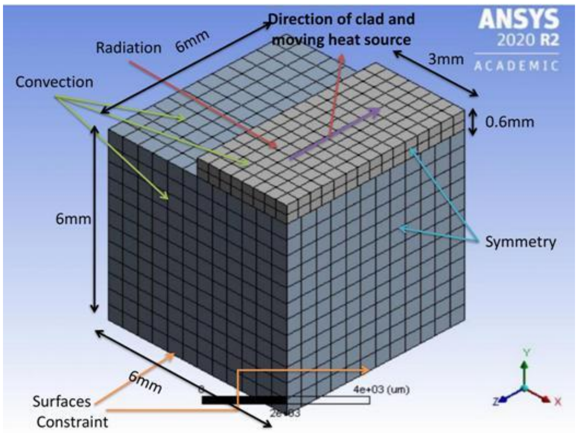

Figure 4. Geometry of 3-D model showing with thermal loading and boundary conditions

In the laser cladding process, the powder injection procedure is adopted to clad over the surface of the substrate material. It's used to model the effect of powder deposition, along with the element birth-death methodology.

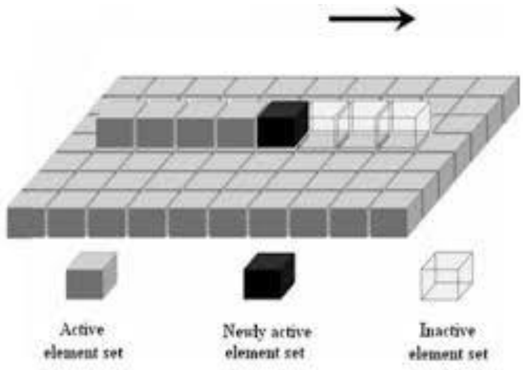

Figure 5. The element birth methodology is used to model powder deposition on the surface of the substrate material during the LC process[5].

3. MODEL VALIDATION

The present model was compared with the previously developed model. The Nodal temperature plots over the work material surface in depth were compared for clad material CPM9V vanadium carbide steel and substrate material H13 tool steel. Even though there were some different temperature values but the trend was quite similar to the previous model. It was observed that the previous model was based on constant the laser power: 1700 Watt, feed rate: 5 gram/min, beam diameter of laser: 3 mm and scanning speed: 200 mm/min[5]. This model was based on the empirical relationship of nodal temperature over depth. Also the previous model took into consideration a varying he figures below predict the difference of nodal temperature with depth distance for materials and a comparison is made between the present data.

3.1 Nodal temperature changes with depth

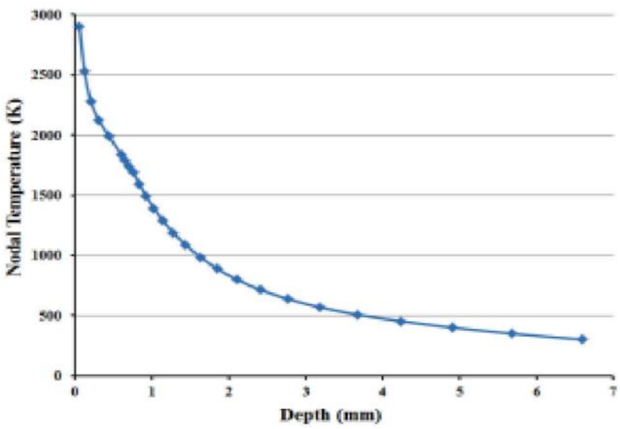

Figure 6. Variation of nodal temperature vs. Depth[5]

1) Nodal temperature changes with depth (input parameter in Ansys)

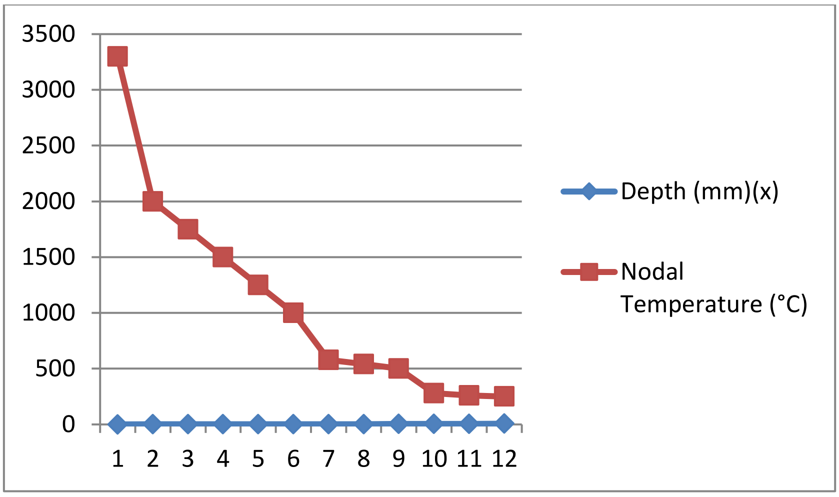

Figure 7. Nodal temperature vs. Depth with input parameter in Ansys.

2) Comparison of nodal temperature with depth

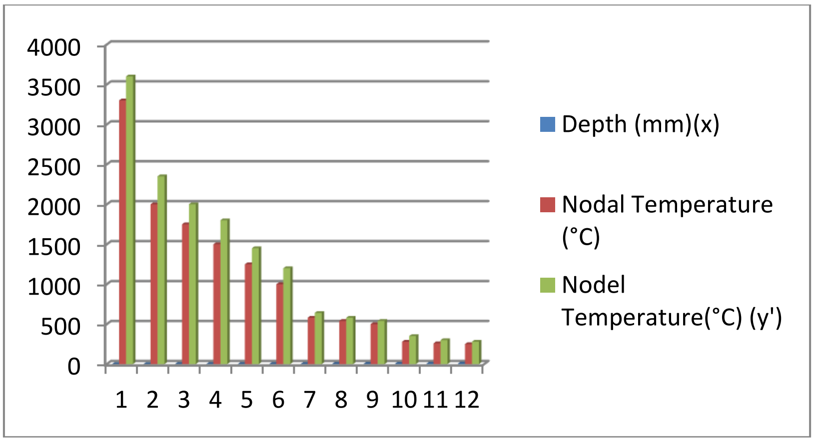

Figure 8. Comparison of nodal temperature vs. depth

Where: Nodal Temperature (^{0}C) taken from literature and Nodal Temperature (^{0}C) (y') input parameter is Ansys.

When comparing the clad height predicted by the 3-D model during the LC process via Ansys simulation to the experimental data, there was a 14 percent variation in the clad height forecast.

4. Study of Parameter Variation of Temperature With Input Parameter

With the laser power (1500–2000) watt input parameter, Ansys software was utilized to model the LC process. The laser beam has a diameter of 3 mm and a scanning speed of 2–4 mm/sec. During the LC process, determine the correlation between thermal and material properties, as well as the thermal gradient.

1) The coupled thermo-mechanical 3-D model predict the coating value for the Beam diameter of laser 3 mm, scanning speed of 240 mm/min, feed rate of 5 gram/min and the laser power of 1200 Watt.

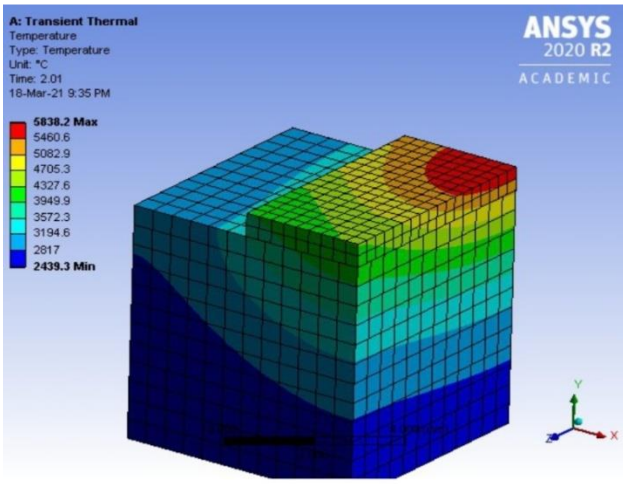

Figure 9. Contour plot of nodal temperature

2) The coupled thermo-mechanical model input parameter for simulation the beam diameter of laser 3 mm, scanning speed of 240 mm/min, feed rate of 5 gram/min and the laser power of 1500 Watt.

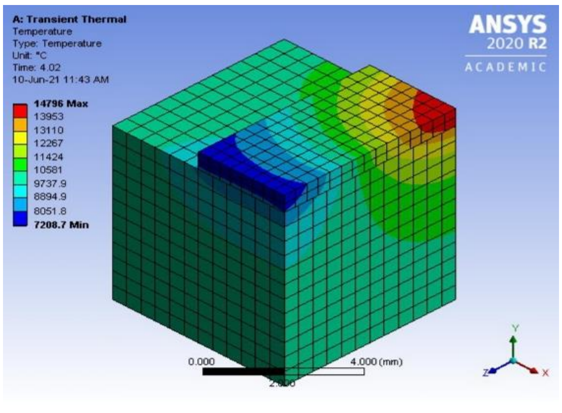

Figure 10. Contour plot of nodal temperature

5. RESULTS

In this chapter I have to show the improvement in the performance and parameters obtain by Finite element analysis of LC process.

5.1 Convection

Table1: Transient thermal analysis (Convection)

Temperature [°C]	Convection Coefficient [W/mm²·°C]
1.	1.24e-006
10.	2.67e-006
100.	5.76e-006
200.	7.25e-006
300.	8.3e-006
500.	9.84e-006
700.	1.101e-005
1000.	1.24e-005

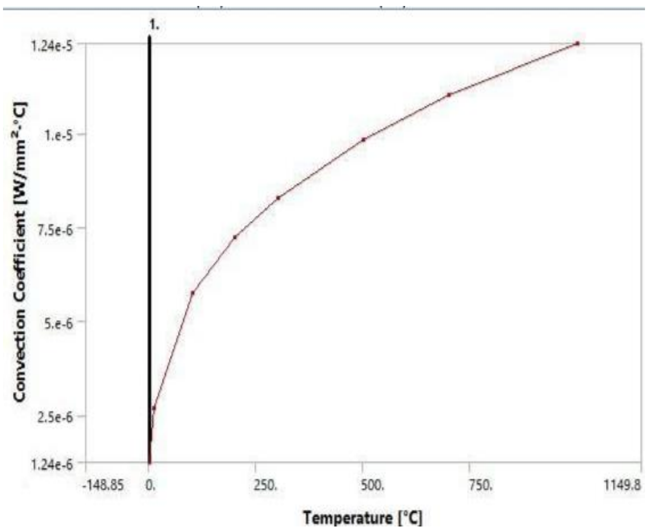

Figure 11. Convection during laser cladding

1) Temperature Distribution

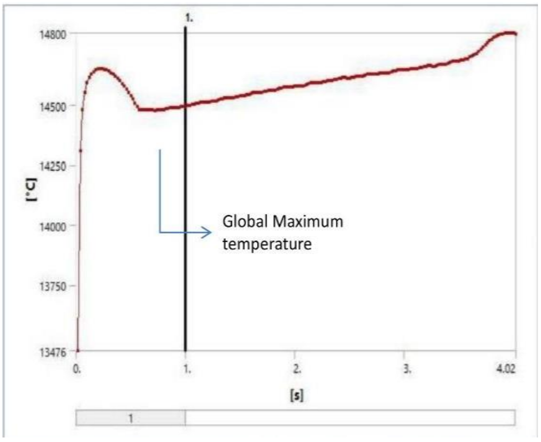

Figure 12. Global maximum temperature by FEM

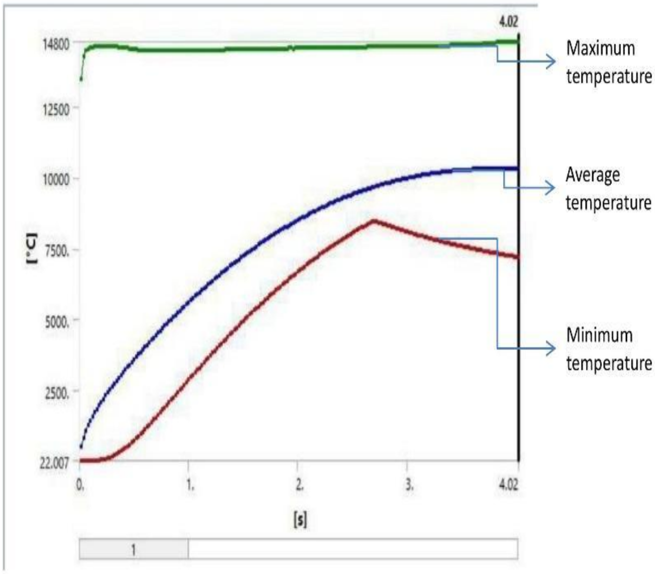

Figure 13. Variation of temperature by FEM

2) Transient Heat Transfer Analysis

1) With increasing laser intensity, the temperature gradient increases, with the largest gradient in the vertical Z direction, followed by the X and Y directions. The thermal gradient in the X and Y directions is smaller in the present FEA results as compared to the Z direction.

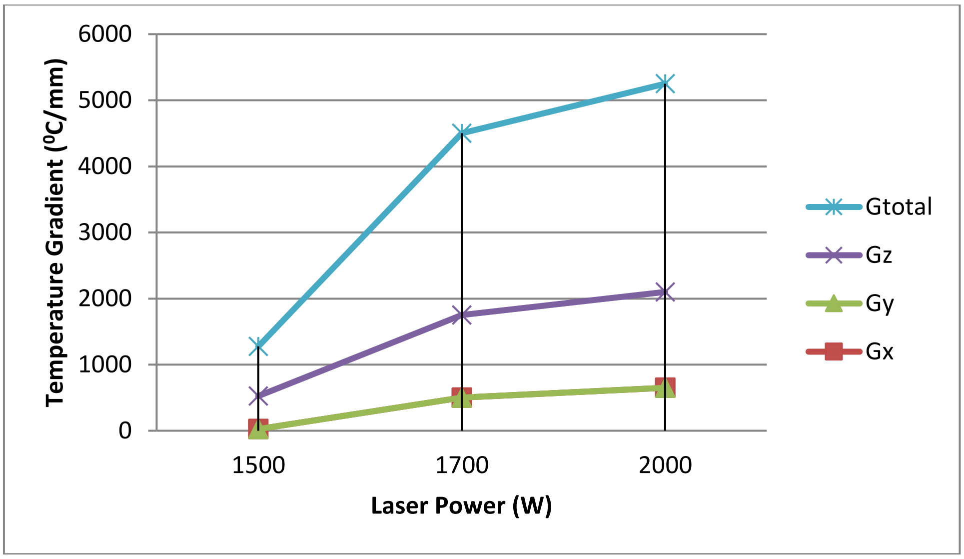

Figure 14. Changes in the simulated thermal gradient as a function of laser power

2) It is computed how scanning speed affects the thermal gradient. The temperature gradient is clearly minimized as the scanning speed increases.

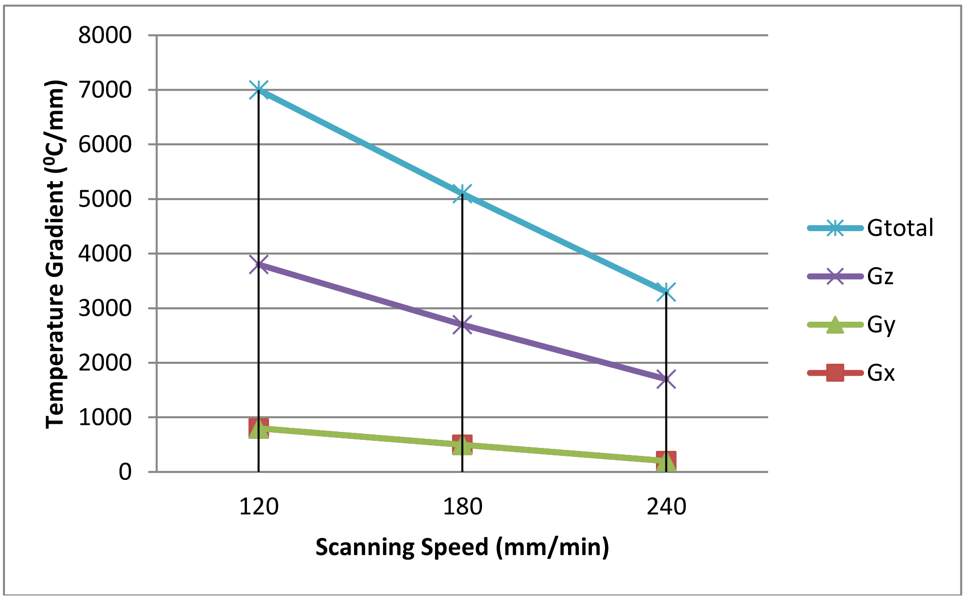

Figure 15. Scanning speed affects the calculated thermal gradient.

Thermal gradients in the x, y, and z directions are represented by G_x, G_y, and G_z, respectively due to LC process clad over the surface of the substrate materials.

6. Discussion

It is observed that temperature gradient of work material increases with increases when the laser power increases. The thermal gradient decreases as the scan speed increases.

- In the present FEA results when the laser power increases 1500Watt - 2000Watt the total temperature gradient increases between 1200 ^{0}C/mm – 5200 ^{0}C/mm. the temperature gradient in X direction and Y direction are obtained on the lower side as compared with Z direction (depth).
- When the scanning speed increases 120 mm/min – 240 mm/mm the total temperature gradient reducing between 7000 ^{0}C/mm – 3200 ^{0}C/mm.

In the LC process, clad material (CPM9V) provides decreased heat distortion, reduced dilation, low porosity levels, and greater surface uniformity over the substrate material (H13). It can be used to create a protective layer as well as restore broken or damaged surfaces.

7. Conclusions

The cladding process' combined thermo-mechanical analysis is built on the concept that the temperature profile produced from thermal analysis may be utilized to predict the temperature distribution across the LC process' duration. A thermal analysis of a process can yield temperature profiles, which can be used to calculate dilution and heat affected zones. In the current FEA results, the temperature gradient in the Z direction is larger than in the X and Y directions. The influence of scanning speed on temperature gradient is greatly reduced as scanning speed increases.

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Biographies

Devendra Kumar Gautam is from Prayagraj, Uttar Pradesh, India**.** He has completed his Bachelor's degree in Mechanical Engineering from Rajkiya Engineering College Azamgarh in 2018, Master's degree in Computer Aidded Design and Manufacturing from MNNITA, Prayagraj in 2021, and Pursuing philosophy of doctorate degree from MNNITA, Prayagraj. His research interests lie in Fatigue damage analysis of alloys and composites.

Dr. Audhesh Narayan is an associate professor in the Department of Mechanical Engineering at Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He received his Ph.D. degree in Mechanical Engineering in 2012 from Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. His current research interests include Conventional and Advanced Machining Processes, Deep Grinding Processes, Hybrid Machining Processes, Micromachining Processes and FEM Applications in Manufacturing.

Dr. Satish Kumar is currently working as an Assistant Professor at Applied Mechanics Department, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He has completed his B. Tech from NIT Jalandhar, M. Tech, and Ph.D. from IIT Roorkee. His research interests lie in the design, fabrication, and mechanical characterization of adaptive membrane-based lightweight structures for space applications, which he plans to study using a combined experimental and numerical approach. He has published seven peer-reviewed journal articles, seventeen international conference papers, and filled two Indian patents. He has successfully completed one research project and three consultancy projects.

Dr. Ajaya Bharti is an associate professor in the Department of Applied Mechanics at Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He received his Ph.D. degree in Applied Mechanics in 2014 from Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. His current research interests include Fatigue and Fracture Mechanics, Wear, Corrosion, Powder Metallurgy, Physical Metallurgy, Synthesis and Characterization of Advanced Materials, Biomaterials, Severe Plastic Deformation (SPD), Structural Health Monitoring.